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Theoretical energy performance evaluation of different single stage vapour compression refrigeration configurations using R1234yf and R1234ze(E) as working fluids

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ABSTRACT

R1234yf and R1234ze(E) have been proposed as alternatives for R134a in order to work with low GWP refrigerants, but this replacement results generally in a decrease of the performance. For this reason, it is interesting to explore ways to improve the system performance using these refrigerants. In this paper, a comparative study in terms of energy performance of different single stage vapour compression configurations using R1234yf and R1234ze(E) as working fluids has been carried out. The most efficient configuration is the one which uses an expander or an ejector as expansion device. On the other hand, using an internal heat exchanger in a cycle which replaces the expansion valve by an expander or an ejector could produce a detrimental effect on the COP. However, for all the configurations the introduction of an internal heat exchanger produces a significant increment on the cooling capacity.

Evaluation théorique de la performance énergétique de différentes configurations monoétagées à compression de vapeur utilisant R1234yf et R1234ze€ comme fluides actifs

Mots clés : Système mono-étagé ; Réfrigération ; R1234yf ; R1234ze(E) ; Efficacité énergétique

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Nomenclature

COP	coefficient of performance
h	enthalpy (kJ kg^{-1})
IHX	internal heat exchanger
$\dot{m}$	refrigerant mass flow rate (kg s^{-1})
N	compressor revolutions (rpm)
P	pressure (kPa)
Q	thermal power (kW)
T	temperature (K)
V	compressor volume (m^3)
W	electric power (kW)

Greek symbols

ε	internal heat exchanger effectiveness
η	efficiency
ρ	density (kg m^{-3})

Subscripts

c	compressor
d	diffuser
e	ejector
em	electromechanical
g	global
is	isentropic
k	condenser
n	nozzle
o	evaporator
s	suction
v	volumetric
x	expander

1. Introduction

Nowadays, chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants have been replaced by hydrofluorocarbon (HFC) refrigerants, with zero ozone depletion potential (ODP), according to the Montreal Protocol (United Nations Environmen, 1997). However, many HFC refrigerants have high global warming potential (GWP) values and they are considered as greenhouse gases under the Kyoto Protocol (Protocol, 1997). As a result, efforts are made in order to search alternative refrigerant for high GWP refrigerants replacement. R1234yf and R1234ze(E) (henceforth it will be referred simply as R1234ze) have been proposed (McLinden et al., 2013) as alternative refrigerants for R134a, which has a GWP of 1430 and is extensively used in refrigeration and air conditioning, especially in mobile air conditioning (MAC). Both refrigerants have an ODP value of zero (World Meteorological Orga, 2006), a GWP value of 4 and 6, respectively (Papadimitriou et al., 2008; Nielsen et al., 2007), low toxicity and mild flammability (Koban and 2009-01). Despite this, some authors (Zilio et al., 2011; Navarro-Esbrí et al., 2012) have reported reductions in the coefficient of performance (COP) and the cooling capacity when using R1234yf as a drop-in replacement for R134a. On the other hand, for R1234ze the results showed a higher COP but lower cooling capacity (Leighton et al., 2012), making R1234ze unsuitable as drop-in replacement due to the requirement of a significantly higher compressor swept volume to achieve the same cooling capacity than R134a.

In this context, various manners of increasing the COP in a vapour compression refrigeration system can be highlighted, such as the increase of the refrigerating effect in the evaporator by means of an internal heat exchanger (IHX) (Domanski et al., 1994), the use of expansion devices which allow to reduce the losses in the expansion stage such as ejectors (Sumeru et al., 2012), or even the use of expanders to reduce system energy consumption by expansion work recovery (Subiantoro and Ooi, 2013). The use of these devices has motivated the study of different configurations in order to improve the cycle efficiency. Navarro-Esbrí et al. (2013) analysed experimentally the influence of an internal heat exchanger on the performance of a vapour compression system using R1234yf as a drop-in replacement for R134a, reporting reductions between 6 and 13% in cooling capacity and COP when R134a is replaced by R1234yf, although the presence of an IHX can help to reduce these reductions. Harrel and Kornhauser (1995) performed an experiment of an ejector as an expansion device in a system using R134a as refrigerant, reporting improvements on the COP over standard cycles between 3.9% and 7.6%. Li et al. (2014) analyse an ejector-expansion refrigeration cycle using R1234yf as refrigerant, highlighting that the cycle outperforms the standard one, especially under extreme working conditions. Lawrence and Elbel (2014); Lawrence and Elbel (2013, 2012); Lawrence (2013) conducted an experimental and analytical investigation of two-phase ejector cycles using low pressure refrigerants R134a and R1234yf, concluding that when compared to a single evaporation temperature expansion valve cycle the ejector cycle showed maximum COP improvements of 6% with R1234yf and 5% with R134a. Robinson and Groll (1998) have reported that an expander increases the COP up to 15% when applied to conventional R22 and R134a systems.

Therefore, the aim of this work is to evaluate theoretically the energy performance of six single stage vapour compression refrigeration configurations using low GWP refrigerants R1234yf and R1234ze as working fluids, including some complex configurations that mix the presence of an IHX with an ejector or an expander. The rest of the paper is organized as follows. In Section 2, the proposed configurations are presented. In Section 3, the results are shown and discussed. Finally, in Section 4, the main conclusions of the paper are summarized.

2. Configurations

This paper focuses on evaluating single stage vapour compression cycle configurations, being the configurations analysed the followings:

a) Basic cycle (BC)